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Operation Manual for the Intensity Based Interrogation of Fibre Bragg Grating Arrays on Vibrating Structures

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DSTO-TN-0985

ABSTRACT

This technical note is provided as a companion document to DSTO TR-2370. The original technical report describes the development and evaluation of an intensity-based demodulation approach for the measurement of strains, induced by structural vibrations, using Fiber Bragg Gratings (FBG). This companion technical note contains a detailed set of operating instructions for interfacing the intensity based demodulation system with a frequency analyser to provide the Frequency Response Functions from a series of FBG arrays attached to a vibrating structure.

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Operation Manual for the Intensity Based Interrogation of Fibre Bragg Grating Arrays on Vibrating Structures

Executive Summary

This technical note is provided as a companion document to DSTO TR-2370. The original technical report describes the development and evaluation of an intensity-based demodulation approach for the measurement of strains, induced by structural vibrations, using fibre Bragg gratings. This companion technical note contains a detailed set of operating instructions for interfacing the intensity based demodulation system with a frequency analyser to provide the Frequency Response Functions from a series of FBG arrays attached to a vibrating structure.

Both this technical note and its companion technical report are formal contributions to an experimental program sponsored by the US Office of Naval Research (ONR) under Grant No.N00014-09-1-0364. The three year program entitled "Structural Health Monitoring Through Environmental Excitation and Optical Fibre Sensors" commenced in December 2008. It is a collaborative research effort involving researchers from the US Naval Academy (NA), Naval Surface Warfare Center (NSWC), the Australian Co-operative Research Centre for Advanced Composite Structures (CRCACS) and DSTO.

The ultimate goal of the program is the demonstration and validation of a large area vibration-based structural health monitoring system on a composite structure using simulated environmental excitation and a network of surface-mounted fibre Bragg gratings for response measurement.

DSTO's involvement in this program is to develop the distributed fibre Bragg grating interrogation system and conduct studies on the reliability, durability and packaging of the fibre Bragg gratings.

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Glossary

ACC	Accelerometer
BNC	Bayonet Neill-Concelman
FBG	Fibre Bragg Grating
FWHM	Full Width Half Max
I/O	Input Output
OF	Optical Fibre
O/P	Output
RHS	Right Hand Side
SIDER	Structural Irregularity and Damage Evaluation Routine

1. Introduction

This document is an operating manual which provides detailed instructions on how to use a custom-built intensity based interrogation system to measure vibrational strains using Fibre Bragg Grating (FBG) arrays. The vibrations may be induced by either an impact hammer or an electrodynamic shaker. It is provided as a companion document to DSTO-TR-2370¹ which describes the design and development of the intensity based interrogation system.

The basic principle of operation for intensity-based interrogation of FBGs involves tuning a narrow line-width laser source to a wavelength corresponding to the midpoint of either the leading or trailing edge of the FBG reflection spectrum. When a strain is applied to the grating the spectrum will shift, causing the transmittance at the tuned wavelength to increase or decrease. This can be quantified by measuring the amount of transmitted or reflected light with a photodiode.

This manual was written to assist the user with setting up both the hardware and software for interfacing the FBG interrogation system with a vibration analyser. The manual also guides the user on how to set-up the vibration analyser to measure the frequency response function for each FBG when exciting a structure with either an instrumented hammer or an electrodynamic shaker.

The data obtained from the frequency analyser can be used by the Structural Irregularity and Damage Evaluation Routine (SIDER) which is a broadband vibration-based technique that uses features in the complex curvature operating shapes of vibrating structures to locate damage and other areas with structural stiffness variation in composites.

The FBG interrogation system can be operated in 3 modes: (i) Manual, (ii) Semi-automatic and (iii) Automatic. The principle of operation for each of these modes is briefly outlined below. Further details may be found in the Appendices of DSTO TR-2370¹.

- (i) Manual mode can only be used with impact hammer excitation. It involves manually scanning a single fibre containing an array of FBGs immediately prior to the experiment. The purpose of this scan is to detect the mid-point locations for each grating on the array and also to measure the slope of the response (calibration factor) surrounding this mid-point. The response from each grating to impact excitation is then recorded in turn with the user manually stepping between gratings after each impact. This process is then repeated for each array on the structure. This mode is recommended for experiments where there is only a single fibre array or for multiple arrays in situations where the environmental conditions may change over the course of the experiment.

¹ P.E. Norman and C.E. Davis, 'An intensity-based demodulation approach for the measurement of strains induced by structural vibrations using Bragg gratings' DSTO-TR-2370, February 2010

- (ii) Semi-automatic mode can also only be used with impact hammer excitation. All the grating arrays attached to the structure under test are scanned in advance of the experiment and saved to a configuration file (one file for each array). The configuration file contains the FBG mid-points and the calibration factors for each FBG on the array. In this mode the configuration files are loaded prior to the experiment and the fibre optic switch box automatically switches between arrays. The only operation required by the user is to switch to the next sensor. This mode is recommended where the environmental conditions are unlikely to change significantly in the time interval between the configuration file being stored and the experiment being conducted.
- (iii) Automatic mode can only be used with continuous shaker excitation. This mode is similar to the semi-automatic mode in that the configuration files for each array are stored in advance of the experiment. However, in this mode the data from the photodiode is acquired for a fixed time window for each grating rather than relying on a trigger from the hammer. Once one grating is interrogated, the tuneable laser source then automatically moves to the next wavelength to interrogate the next grating.

2. Instructions for interfacing the FBG interrogator with a vibration analyser for use with impact hammer excitation

This chapter provides detailed instructions for interfacing the intensity based FBG interrogation system with a vibration analyser (OROS-763 V4.41) and using an impact hammer to excite the structure. Instructions are also provided on how to acquire the frequency response information using the FBG arrays (and also accelerometers (acc) if required).

2.1 Configuration of the hardware

Figure 2.1 shows a schematic diagram of the hardware set-up for measuring the vibrational response to impact excitation from a structure using FBGs and analysing this response using a vibration analyser.

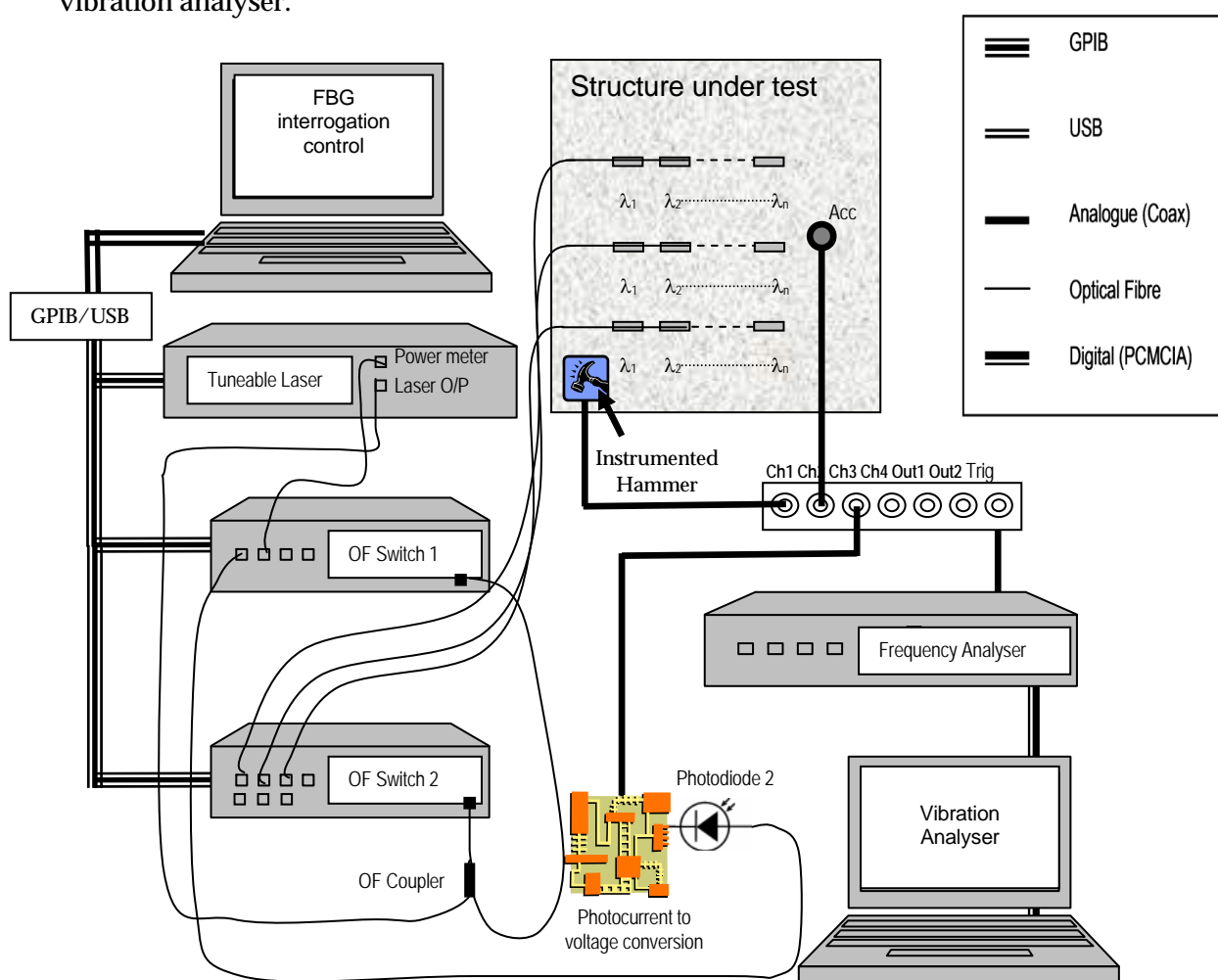


Figure 2.1: Schematic diagram showing the intensity based interrogation set-up with the vibration analyser using hammer excitation

2.2 Starting the OROS vibration analysis software

Prior to running the software, ensure all the hardware is set-up and switched on as shown in Figure 2.1. The password for the tuneable laser is 1234. Open the OROS software² by running the file OR763.exe (Version 4.41) located on desktop.

N.B. If the laptop goes into hibernation on standby mode while the OROS software is running, there will be a driver calling error the next time the software is opened. This can be corrected by ejecting the PCMCIA from its slot, replacing it and then re-starting the software. If the error occurs again, restart the laptop and reopen the program.

2.3 Creating a Project

This sets up the primary folder into which all the data and configuration files are stored. Any details about the test article and experiment design should be entered at this stage in the comments section.

1. Choose a New Project and then click OK
 - Enter Project name
 - **Directory:** The usual location is C:\ProgramFiles\0R25\Project
 - Enter comments as required
2. Click next
3. Enter a Sub Project Name: (The sub project is usually used to store individual tests which are carried out within the main experiment.)
4. Click next (It may take a while to open the next window)

2.4 Input Front End Setup

This sets up the front end inputs for the OROS analyser. The range, data type and any scaling factors for each active channel are set-up at this stage. To demonstrate the process, the example shown in Figure 2.1 is used where channel 1 is the force (hammer), channel 2 is the accelerometer (Acc) and channel 3 is the photodiode.

1. Click on Select Active Inputs, and select inputs being used and then click OK.
2. Click on channel 1 tab and set-up the channel as outlined below:
 - **Range:** 310 mV (this may need to be adjusted depending on the impact level)
 - **Physical Unit:** Force, N (if channel 1 is being set-up as a hammer input)
Note: Although the unit reported is Newtons, the calibrations for the OROS are actually in lbs.
 - **Transducer Reference:** Endevco Modal Hammer (This may need to be adjusted depending on the hammer type used)
 - **Coupling:** ICP (use ICP for hammer, shaker, accelerometer)

² The software is currently located on the laptop with DSTO Asset No. AAN 25738

3. Click on channel 2 tab and set-up the channel as outlined below:
 - **Range:** 310 mV (this may need to be adjusted depending on the impact level)
 - **Physical Unit:** Acceleration meter, g
 - **Transducer Reference:** (Enter the accelerometer details here)
 - **Coupling:** ICP (use ICP for hammer, shaker, accelerometer)
4. Click on channel 3 tab and set-up the channel as outlined below:
 - **Range:** 310 mV (this may need to be adjusted depending on the impact level)
 - **Physical Unit:** Voltmeter, V
 - **Transducer Reference:** Sensor 3
 - **Coupling:** AC (use AC for the Photodiode and Strain Gauge Output)
5. Click next

2.5 Input Pre-process

This stage of the process sets up the name for each active channel and defines which channel is used as the reference channel for data analysis.

1. Set the number of preprocesses input to the number of channels being used.
2. Select Preproc. 1 tab
 - Input Channel: Ch.1
 - Preprocess Name: Hammer
 - Ensure the box is checked for channel 1 as the reference (if channel 1 is the hammer input)
3. Select Preproc. 2 tab
 - Input Channel: Ch.2
 - Pre-process Name: Accelerometer
4. Select Preproc. 3 tab
 - Input Channel: Ch.3
 - Pre-process Name: FBG
5. Click next until the Create a New Measure page is reached

2.6 Create a New Measure

This sets-up a new folder within the sub-project folder where all the data files are saved to. The type of analysis to be applied to the data is also specified here.

1. Enter **Measure Name:** (Any name. For example, the date)
2. Select **Analyser Mode:** For example, Real Time FFT Analyzer
3. Insert any comments as required
4. Click Next

2.7 Analyser Setup

This sets-up the parameters for the data analysis.

1. Click on Frequency/Zoom setup tab
2. Set **Frequency Range**: (Typically 0–2 kHz for this application)
3. Click on Analysis tab
4. Set the following:
 - **Overlap**: Retrigger
 - **Window set 1**: Force
 - **Window set 2**: Response
 - **FFT Resolution**: 3201
5. Look on the right at the Response Window graph
 - Click on line 2 and drag to the far left
 - Click on line 4 and drag to the far right
 - Click on line 3 and adjust so that the yellow curve decays to zero as shown in Figure 2.7.1



Figure 2.7.1: Response Graph Window

6. Click on average tab
7. Set the following:
 - **Mode**: Linear
 - **Number**: The number of times the specimen will be excited to have its average determined, i.e. setting Number to 2, the user will tap the specimen twice and the OROS will calculate the average of the 2 taps (The user must press enter or the number will not update)
8. Click Next

2.8 Trigger Setup

This sets up the triggering for the frequency analyser.

1. Click on Trigger Mode Tab
2. Set the following:
 - Trigger Mode: Level
 - Validation Mode: Manual
3. Click on Input Level Tab
4. Set the following:
 - Input level: 5%
 - Delay: -0.02 (actual delay will be calculated on resolution)
5. Click OK

2.9 Setting-up the Main Display Window

This sets up the front panel for viewing the data on the frequency analyser while conducting the experiments. The windows which the user needs to display will depend on the active input channels and the types of sensors being used. To demonstrate the process, the example shown in Figure 2.1 is used where channel 1 is the force (hammer), channel 2 is the accelerometer and channel 3 is the photodiode.

1. Close all graph windows
2. Click on window in the menu bar and select New Window
3. Choose the following by double clicking the window name(s) required: (other windows may be selected as required)
 - **Trigger:** Hammer and FBG
 - **Spectrum:** Hammer
 - **FRF-H1:** FBG
 - **Coherence:** FBG
4. Click OK
5. Click on window in the toolbar and select Tile Horizontal
6. Your window should appear as in Figure 2.9.1
7. Click on the green play button, located on the top left hand side of the OROS window.

The OROS frequency analyser is now configured and ready to start acquiring data. The next stage is to set-up the FBG interrogator.

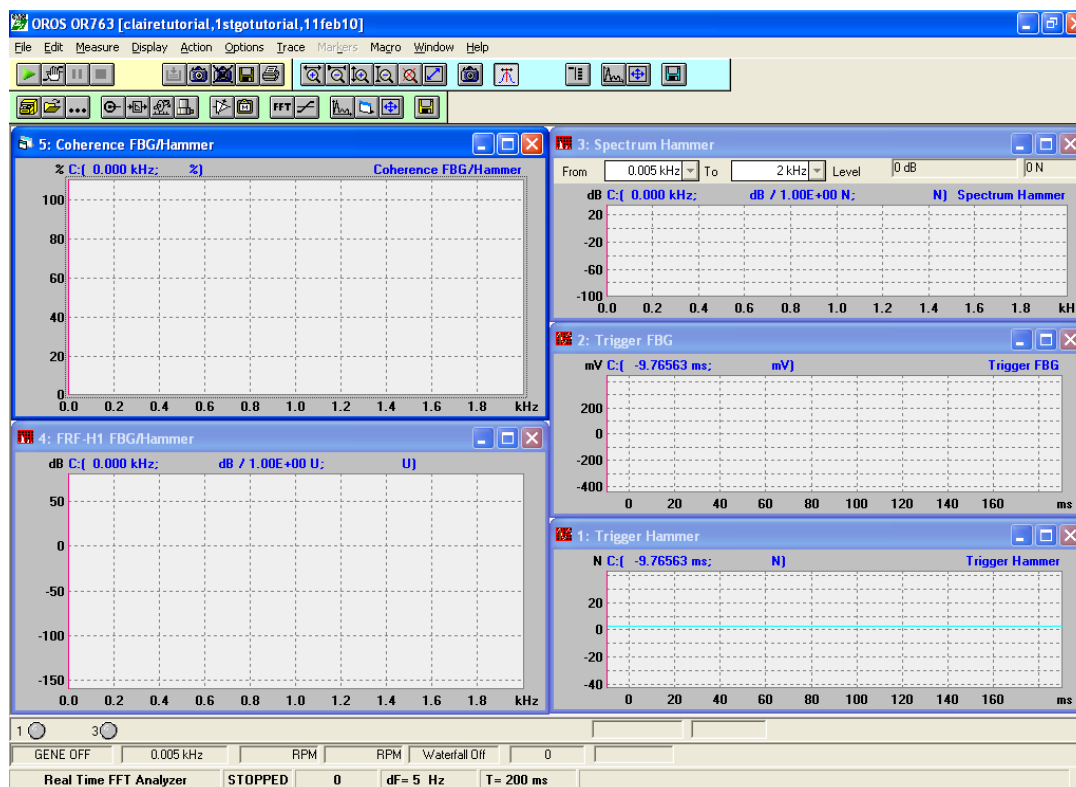


Figure 2.9.1: Screen capture of the OROS frequency analyser set-up for measurement of the FRF for an accelerometer and an array of FBG's

2.10 Starting the Agilent 8164A Control program

1. Open the software³ using the Agilent 8164A Control icon located on the desktop
2. Confirm that the I/O configurations are as shown in Figure 2.10.1 and select continue.
Note: These should correspond to the GPIB addresses assigned on the actual instruments

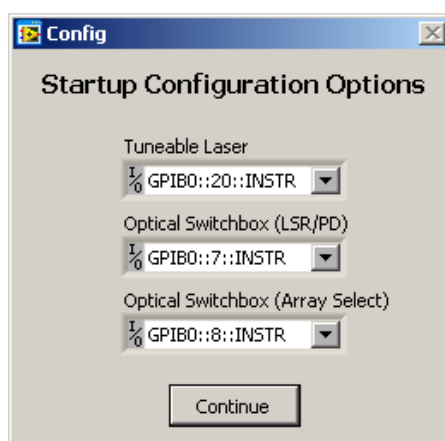


Figure 2.10.1: Start-up Configuration Options

³ The software is located on the laptop with DSTO Asset No. AAN 25711

2.11 Configuration for the Agilent 8164A

The following procedure sets up the scanning wavelength range, output power levels and wavelength resolution for the tuneable laser as well as defining the optical switch allocations for the laser source and photodiode.

1. Click on the Configuration tab of the window shown in Figure 2.11.1

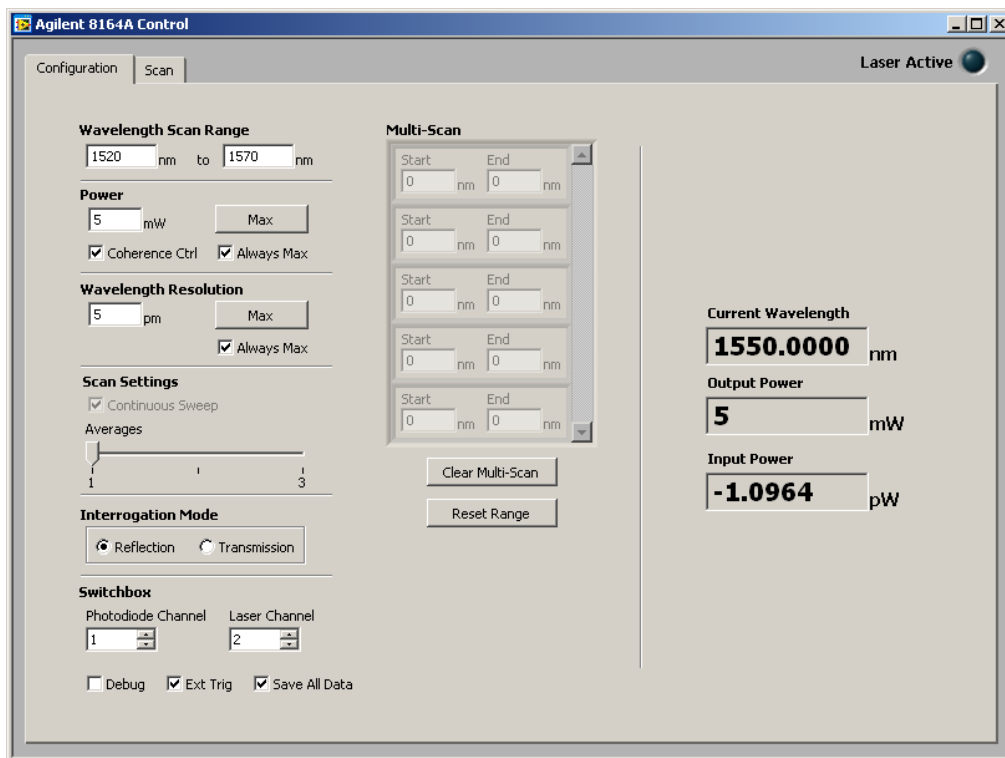


Figure 2.11.1: Configuration window on Agilent 8164A control software

2. Set the following:
 - Wavelength Scan Range: 1520–1570 nm
 - Power: (1) Ensure the 'Always Max' box is checked unless manual configuration is necessary, in which case set the power output level of the laser to what is desired. (2) Enable 'Coherence Ctrl'
 - Wavelength Resolution: Ensure the 'Always Max' box is checked unless manual configuration is necessary, in which case set the wavelength resolution to what is desired
 - Interrogation Mode: Reflection (if the system is set-up to measure the gratings in reflection)
 - Switchbox: Set the channels on switchbox 1 to match the fibre-optic inputs and check the 'Ext Trig' and 'Save All Data' boxes

2.12 Scan the Array

This scans the laser source across all the FBGs in the array and locates the grating peaks and mid-point locations.

1. Click the Scan tab (Figure 2.12.1)

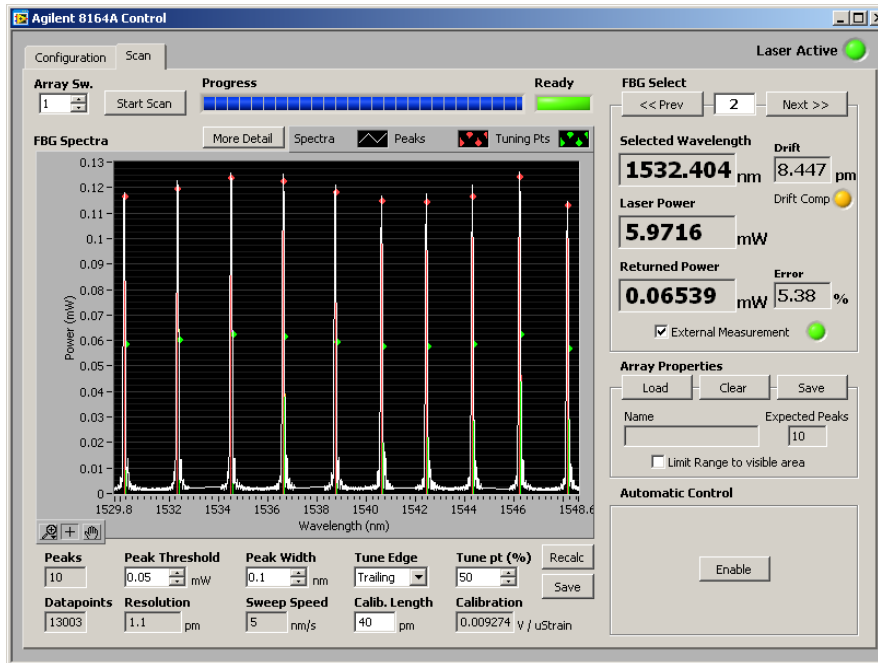


Figure 2.12.1: Scan window on Agilent 8164A control software

2. Select the switch number to which the array is connected (**Array Sw.**)
3. Click Start Scan (This may take up to a minute depending on the scan range)
4. Peaks are indicated by a red dot on the array plot and the number of peaks detected is indicated at the peaks display on Figure 2.12.1. If all peaks are detected skip to step 8
5. If all peaks are not detected, set the **Peak Threshold** limit to half the maximum power level of the FBG reflection peaks.
6. Set the **Peak Width** to approximately half the Full Width Half Max (FWHM) of the FBGs being interrogated
7. Click Start Scan (This may take up to a minute depending on the scan range). **Note:** If a large number of oscillations are visible in the reflection spectrum and the number of peaks does not match the number of gratings, the fibre or patch cord may be damaged.
8. Click More Detail (This may take up to a minute depending on the scan range)
9. Save the **Array Properties** (if you are using Automatic or Semi-automatic Control remember the name given to each array, as you will need to use this later)
10. You may also choose to record the spectral profile of the array as a text file and as an image for further analysis by clicking on the save button at the bottom of the scan window.
11. If the experiment is to be conducted using Semi-Automatic Control, skip to section 2.14, if using Manual Control continue with section 2.13

2.13 Hammer excitation test using manual mode

1. Press F5 on the laptop with the OR763 V4.41 program running to initiate the testing sequence.
2. Hit the specimen with the instrumented hammer. If the load cell in the hammer records multiple hits or if the impact is too light or heavy this will be indicated in the **Trigger Hammer** window. If the impact is unsuitable press F3 on the keyboard to decline this result and impact the specimen again. If the impact is good, press F2 to accept the data. Repeat this process until the number of averages set-up in the analyser window (section 2.7) has been reached.
3. Once the result for the particular FBG sensor has been obtained, click on File menu and select Export result setting. Select desired data (i.e. Coherence, FRFs [Real and Imaginary] for SIDER) to save and set the required file format (i.e. *AE2 format for SIDER analysis or *txt format for Matlab or Excel analysis). **Note:** Once this has been initially configured you can save subsequent results by pressing F9 on the keyboard after each test.
4. Once saved, progress to the next FBG in the array by selecting next on the **FBG Select** input at the top right hand side of the Agilent 8164A scan window as shown in Figure 2.12.1. Repeat steps 1 to 4 in section 2.13 until all the sensors on the array have been measured.
5. The manual test for this array is now completed. If there is more than one array on the specimen to be measured, go to Configuration tab again, and click on Reset Range. Repeat steps 1 to 11 in section 2.12, to measure the properties on the next array and then record the data from the next array as described in section 2.13. Repeat this process until all arrays on the specimen have been measured. (Remember to reset range for every array and to save profiles or record calibration factors for each FBG)

2.14 Hammer excitation test using semi-automatic mode

In semi-automatic mode all the gratings arrays attached to the specimen under test are scanned in advance of the experiment and saved to a configuration file (one file for each array).

1. Save the configuration files for each array attached to the specimen using the steps 2 to 10 as described in section 2.12.
2. Once all the arrays have been scanned and their configuration file saved, click the Enable button in the automatic control window on the bottom Right Hand Side (RHS) of the Scan tab window.

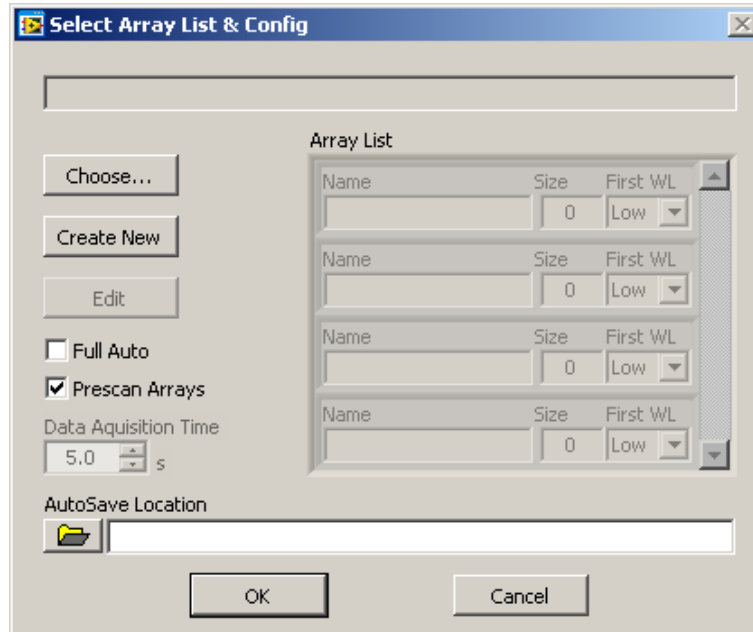


Figure 2.14.1: Array list Selector/Auto mode configuration

3. Select Array List & Config
 - i. Uncheck 'Full Auto' box if you are using the interrogation system in semi-automatic mode (Figure 2.14.1)
 - ii. Check the 'Prescan Arrays' box
 - iii. Click the folder which says AutoSave Location, and type in a name and click save (This will be the folder where all the results will be saved)
 - iv. Click Create New
4. Create/Edit array list
 - i. In the first Name input field (Figure 2.14.2), type in the name of the *.xml file (just the core filename, not the extension) as saved previously in step 9 in section 2.12
 - ii. Select the number of FBGs on the array in the size window
 - iii. Select Low if the first sensor is at the lowest wavelength, select High if sensor one is at the highest wavelength
 - iv. Repeat steps i to iii, above, for other arrays (This is limited by switchbox capacity. Arrays MUST be connected to switchbox in the same order as they appear in this list)
 - v. Click on save then save the list of arrays in the same folder as the configuration *.xml files
 - vi. Click Finished to return to array list selector (Figure 2.14.1)
 - vii. Click OK on the **Select Array List & Config** page to return to the Scan tab

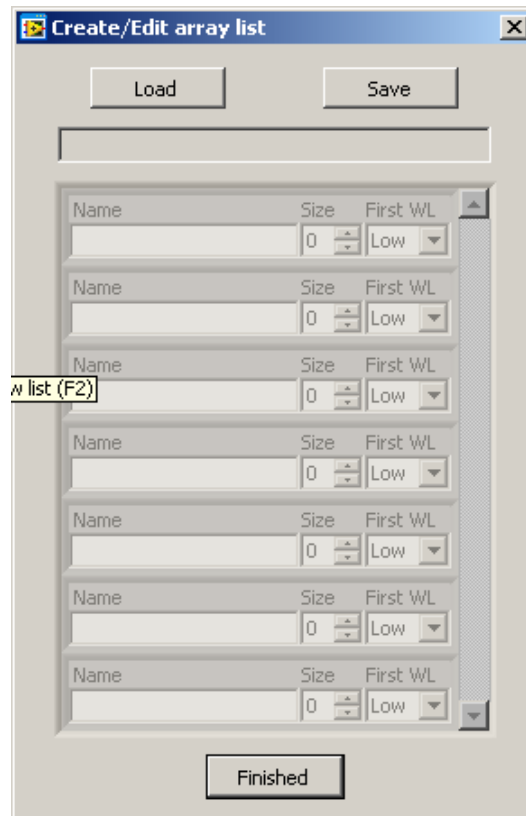


Figure 2.14.2: Array list editor

5. Automatic Control in the Scan tab

- Back in the Scan tab, the **Automatic Control** is shown as Figure 2.14.3, click start

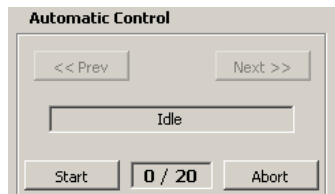


Figure 2.14.3: **Automatic Control** mode in idle stage

- Wait until the prescan is complete, this will take a few minutes depending on how many arrays are being utilised, during this time you can pause or abort. (See Figure 2.14.4)

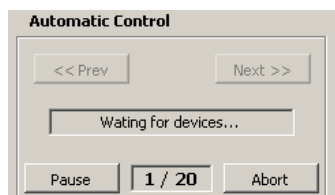


Figure 2.14.4: **Automatic Control** mode in prescan stage

- Once the prescan is complete as seen in Figure 2.14.5, click continue.

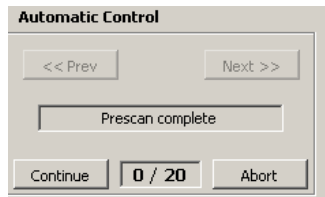


Figure 2.14.5: *Automatic Control* mode in complete stage

The Hammer excitation test in semi-auto mode is now ready for data capture. Hit the specimen with the instrumented hammer. If the load cell in the hammer records multiple hits or if the impact is too light or heavy this will be indicated in the **Trigger Hammer** window. If the impact is unsuitable press F3 on the keyboard to decline this result and impact the specimen again. If the impact is good, press F2 to accept the data. Repeat this process until the number of averages set-up in the analyser window (section 2.7) has been reached.

Once the result for the particular FBG sensor has been obtained, click on File menu and select Export result setting. Select desired data (i.e. Coherence, FRFs [Real and Imaginary] for SIDER) to save and set the required file format (i.e. *AE2 format for SIDER analysis or *txt format for Matlab or Excel analysis.) **Note:** Once this has been initially configured you can save subsequent results by pressing F9 on the keyboard after each test.

Once saved, progress to the next FBG in the array by selecting Next>> button on the **Automatic Control** window as shown in Figure 2.14.6. Repeat steps 6 to 8 in section 2.14 until all the sensors in the array list have been measured.

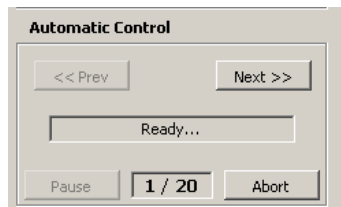


Figure 2.14.6: *Automatic Control* mode in ready stage

3. Instructions for interfacing the FBG interrogator with a vibration analyser for use with shaker excitation

This chapter provides detailed instructions for interfacing the intensity based FBG interrogation system with a vibration analyser (OROS-763 V4.41) and using an electrodynamic shaker to excite the structure. Instructions are also provided on how to acquire the frequency response information for a fixed time interval using the FBG arrays (and also accelerometers (acc) if required).

3.1 Configuration of hardware

Figure 3.1 shows a schematic diagram of the hardware set-up for measuring the vibrational response to excitation from an electrodynamic shaker using FBGs and analysing this response using a vibration analyser.

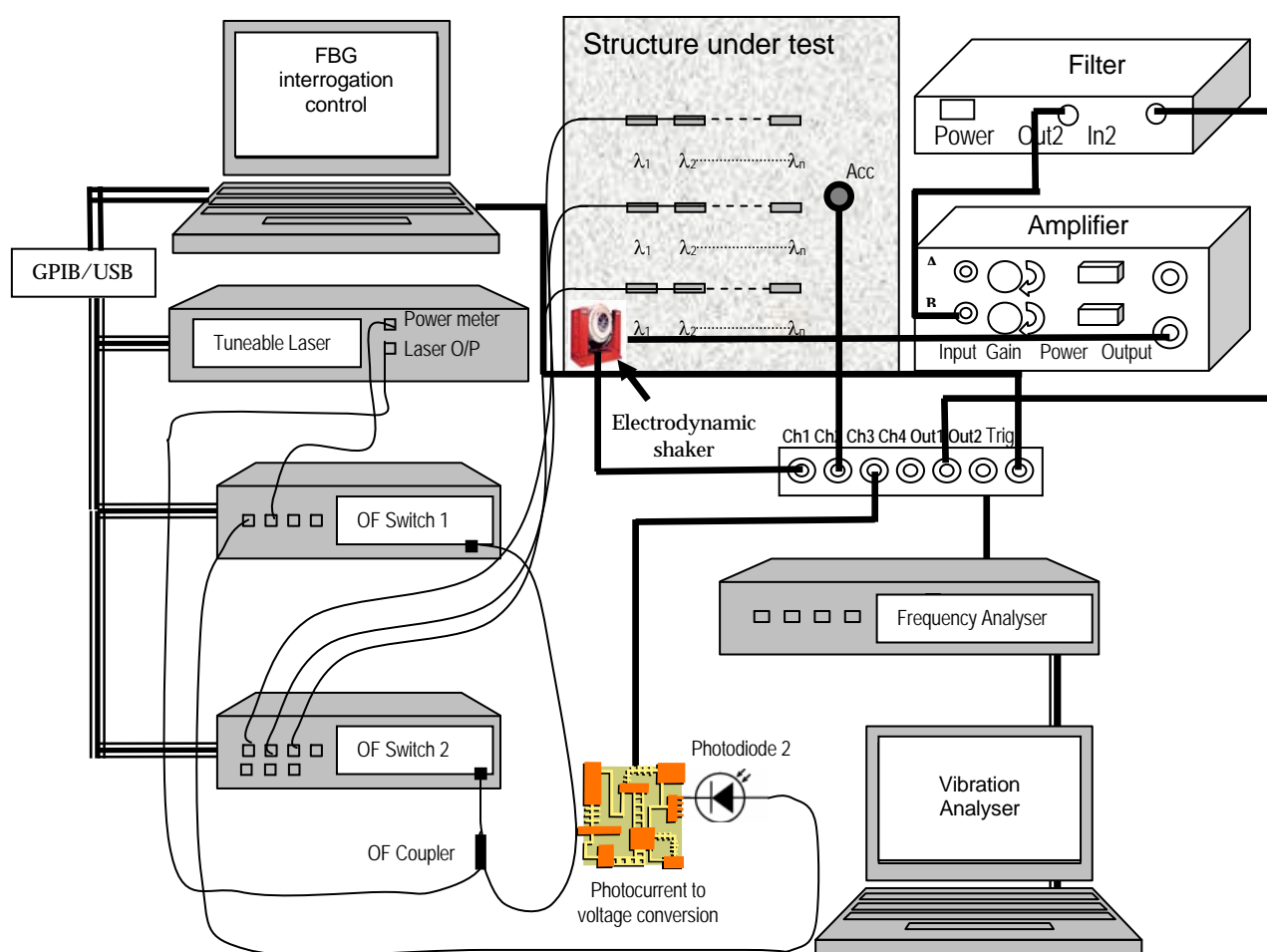


Figure 3.1: Schematic diagram showing the intensity based interrogation set-up with the vibration analyser using shaker excitation (wiring legend as per Figure 2.1).

3.2 Starting the OROS vibration analysis software

Prior to running the software, ensure all the hardware is set-up and switched on as shown in Figure 3.1. The password for the tuneable laser is 1234. Open the OROS software⁴ by running the file OR763.exe (Version 4.41) located on desktop.

N.B. If the laptop goes into hibernation on standby mode while the OROS software is running, there will be a driver calling error the next time the software is opened. This can be corrected by ejecting the PCMCIA from its slot, replacing it and then re-starting the software. If the error occurs again, restart the laptop and reopen the program.

3.3 Setting the external filtering and gain

1. Always start with the gain on the amplifier at 0.
2. To change the setting on the universal Digital Filter press the up or down button of the cursor and change the setting by adjusting the main control dial on the right hand side of the screen.
3. Set the following: (This can change depending on what analysis is needed)
 - **Filter:** Linear-Phase Bandpass
 - **Low Freq:** 150 Hz
 - **High Freq:** 2000 Hz
 - **Transition Slope:** 5.6 dB/Hz
 - **Stopband Attenuation:** MAX
4. To increase the transition slope of the filter, select bandwidth and decrease the frequency range of the bandpass.

3.4 Creating a Project

This sets up the primary folder into which all the data and configuration files are stored. Any details about the test article and experiment design should be entered at this stage in the comments section.

1. Choose a New Project and then click OK
 - Enter Project name
 - **Directory:** The usual location is C:\ProgramFiles\0R25\Project
 - Enter comments as required
2. Click next
3. Enter a Sub Project Name: (The sub project is usually used to store individual tests which are carried out within the main experiment.)
4. Click next (It may take a while to open the next window)

⁴ The software is currently located on the laptop with DSTO Asset No. AAN 25738

3.5 Input Front End Setup

This sets up the front end inputs for the OROS analyser. The range, data type and any scaling factors for each active channel are set-up at this stage. To demonstrate the process, the example shown in Figure 3.1 is used where channel 1 is the input from the load cell attached to the shaker, channel 2 is the accelerometer and channel 3 is the photodiode.

1. Click on Select Active Inputs and select inputs being used and then click OK.
2. Click on channel 1 tab and set-up the channel as outlined below:
 - **Range:** 100 mV (this may need to be adjusted depending on the excitation level)
 - **Physical Unit:** Force, N (if channel 1 is being set-up as a shaker input) **Note:** Although the unit reported is Newtons, the calibrations for the OROS are actually in lbs.
 - **Transducer Reference:** PCB 208C02 SN: 22476 (This may need to be adjusted depending on the shaker being used)
 - **Coupling:** ICP (use ICP for hammer, shaker, accelerometer)
3. Click on channel 2 tab and set-up the channel as outlined below:
 - **Range:** 310 mV (this may need to be adjusted depending on the excitation level)
 - **Physical Unit:** Acceleration meter, g
 - **Transducer Reference:** (Enter the accelerometer details here)
 - **Coupling:** ICP (use ICP for hammer, shaker, accelerometer)
4. Click on channel 3 tab and set-up the channel as outlined below:
 - **Range:** 310mV (this may need to be adjusted depending on the excitation level)
 - **Physical Unit:** Voltmeter, V
 - **Transducer Reference:** Sensor 3
 - **Coupling:** AC (use AC for the Photodiode and Strain Gauge Output)
5. Click next

3.6 Input Pre-process

This stage of the process sets up the name for each active channel and defines which channel is used as the reference channel for data analysis.

1. Set the number of preprocesses input to the number of channels being used.
2. Select Preproc. 1 tab
 - Input Channel: Ch.1
 - Preprocess Name: Shaker
 - Ensure the box is checked for Channel 1 as the reference (if Channel one is the shaker input)
3. Select Preproc. 2 tab
 - Input Channel: Ch.2
 - Pre-process Name: Accelerometer
4. Select Preproc. 3 tab
 - Input Channel: Ch.3
 - Pre-process Name: FBG
5. Click next until the Create a New Measure page is reached

3.7 Create a New Measure

This sets-up a new folder within the sub-project folder where all the data files are saved to. The type of analysis to be applied to the data is also specified here.

1. Enter **Measure Name:** (Any name. For example, the date)
2. Select **Analyser Mode:** (usually “recorder” for use with the shaker in automatic mode)
3. Insert any comments as required
4. Click Next

3.8 Analyser Setup

This sets-up the parameters for the data analysis.

1. Click on the Generator tab
2. Set **Generator Mode:** Random Noise
3. Ensure the box is checked for “Same As FFT size”
4. Click Next

3.9 Record Setup

This sets up the number of records and the record length for the recording.

1. Click on Record tab
2. Set the following:
 - **Number:** Total number of gratings, i.e. 5 arrays, 10 gratings in each therefore 50 records (Press Enter or number will not update)
 - **Size of 1 record:** 20 s or the appropriate time interval required for the data acquired per sensor (Press Enter or number will not update)
3. Click on Recorder Frequency Range Tab
4. Set **Frequency Range:** 0–2 kHz
5. Click Next

3.10 Trigger Setup

1. Click on Trigger Mode Tab
 - Set Trigger Mode: Level
 - Click on Input Level Tab
 - Set Delay: 0 s
 - Set Input level Channel: External
2. Click on External Trigger Setup
3. Set the following:
 - **Coupling:** DC + 1/10
 - **Threshold level:** 2%
 - **Hysteresis:** 50 mV
 - Click OK
4. Click OK

3.11 Setting-up the Main Display Window

This sets up the front panel for viewing the data on the frequency analyser while conducting the experiments. The windows which the user needs to display will depend on the active input channels and the types of sensors being used.

1. Click on window in the menu bar and select Tile Horizontal

The window should appear as in Figure 3.11.1 (with an active window for each active input selected at the input front end set-up stage). **Note:** At this point it may be desired to tune the laser to an FBG, run the shaker at the desired gain and check if the individual channel gains for each sensor are set appropriately.

2. Click on the green play button, under the toolbar
3. Enter a File Name (this is the *.wav file where the data is saved)
4. Click OK

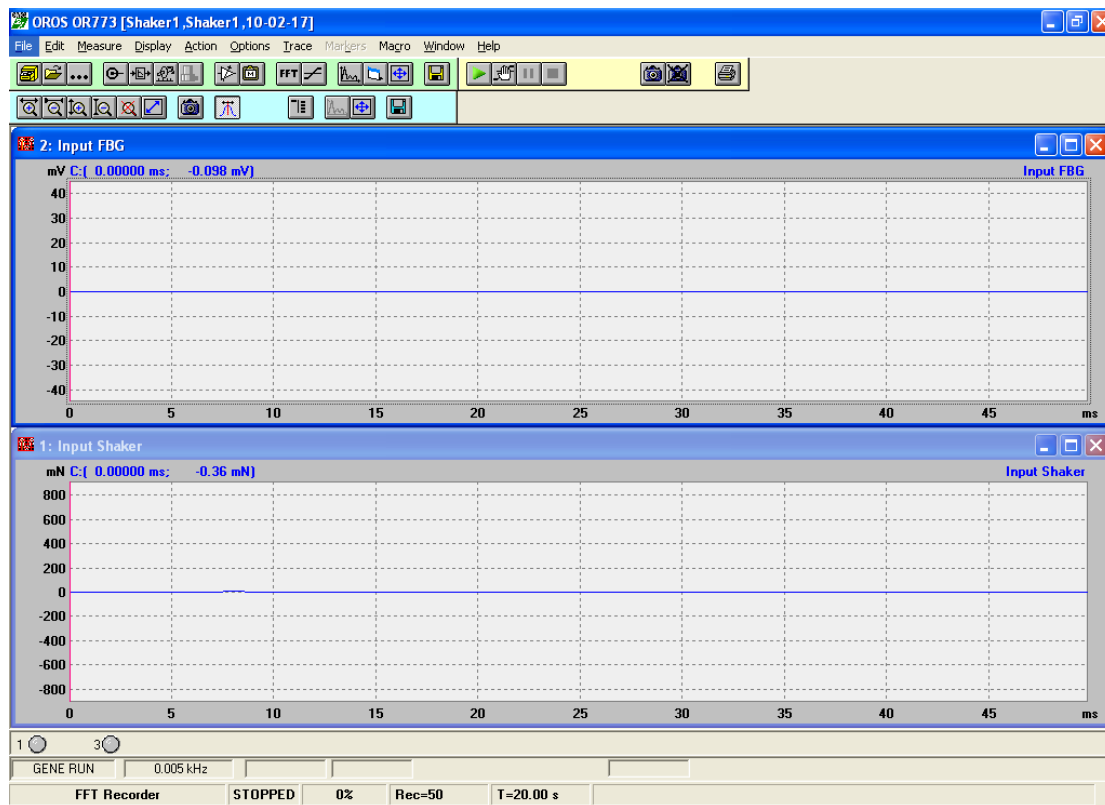


Figure 3.11.1: Main screen of the OROS frequency analyser where the active inputs (i.e. Shaker and FBG) appear on the graph

The OROS frequency analyser is now configured and ready to start measuring. The next stage is to set-up the FBG interrogator.

3.12 Starting the Agilent 8164A Control program

1. Open the software⁵ using the Agilent 8164A Control icon located on the desktop
2. Check if the I/O configurations are as shown in Figure 3.12.1 and select continue.
Note: These should correspond to the GPIB addresses assigned on the actual instruments.

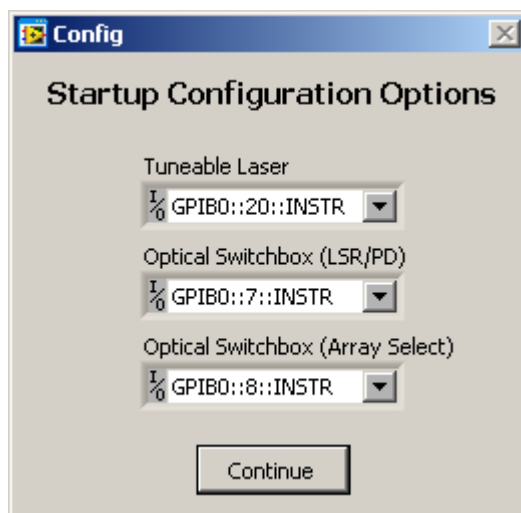


Figure 3.12.1: Start-up Configuration Options

3.13 Configuration for the Agilent 8164A

This stage of the process sets-up the scanning wavelength range, output power levels and wavelength resolution for the tuneable laser as well as defining the optical switch allocations for the laser source and photodiode.

1. Click on the Configuration tab of the window shown in Figure 3.13.1

⁵ The software is located on the laptop with DSTO Asset No. AAN 25711

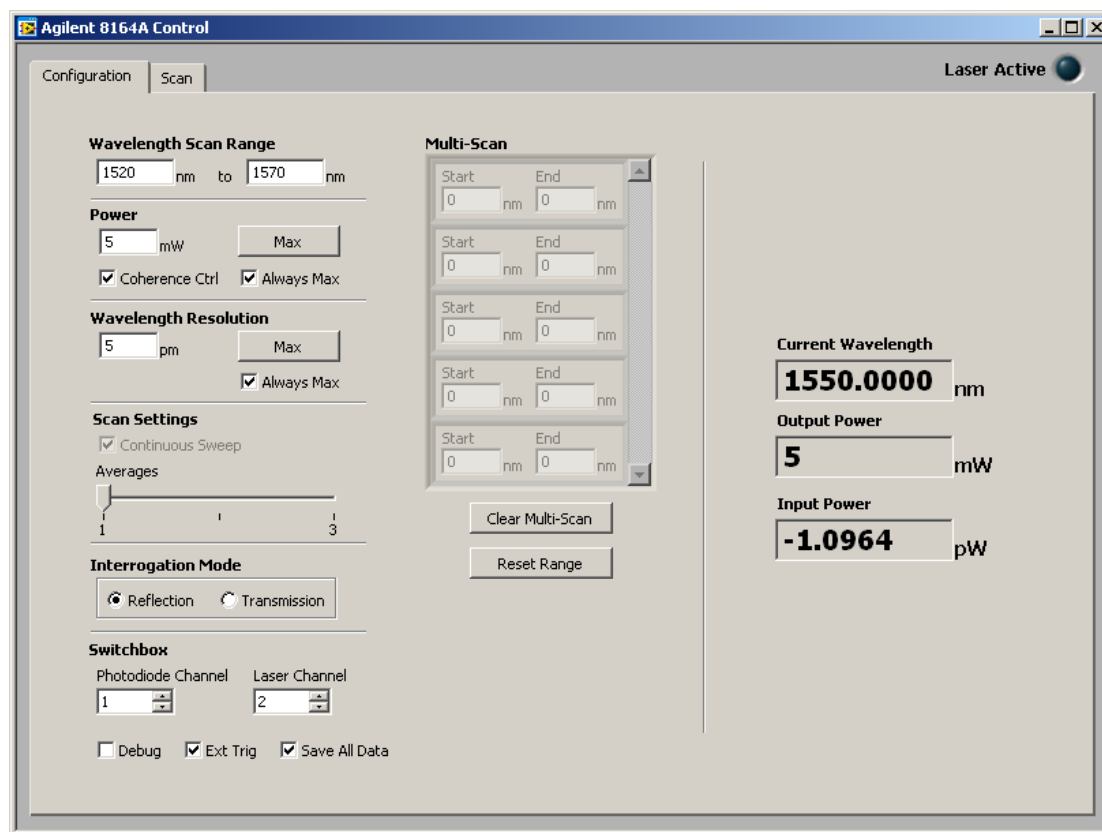


Figure 3.13.1: Configuration window on Agilent 8164A control software

2. Set the following:

- Wavelength Scan Range: 1520–1570 nm
- Power: (1) Ensure the 'Always Max' box is checked unless manual configuration is necessary, in which case set the power output level of the laser to what is desired. (2) Enable 'Coherence Ctrl'
- Wavelength Resolution: Ensure the 'Always Max' box is checked unless manual configuration is necessary, in which case set the wavelength resolution to what is desired
- Interrogation Mode: Reflection (if the system is set-up to measure the gratings in reflection)
- Switchbox: Set the channels on the switchbox 1 to match the fibre-optic inputs and check the 'Ext Trig' and 'Save All Data' boxes

3.14 Scan the Array

This scans the laser source across all the FBGs in the array and locates the grating peaks and mid-point locations.

1. Click the Scan tab (Figure 3.14.1)

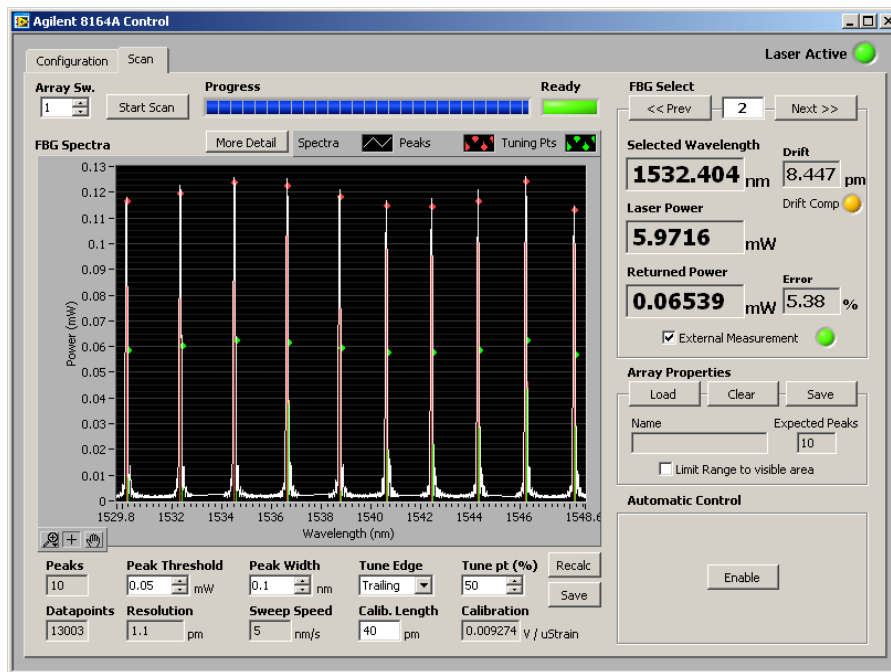


Figure 3.14.1: Configuration window on Agilent 8164A control software

2. Select the switch number to which the array is connected (**Array Sw.**)
3. Click Start Scan (This may take up to a minute depending on the scan range)
4. Peaks are indicated by a red dot on the array plot and the number of peaks detected is indicated at the peaks display on Figure 3.14.1. If all peaks are detected skip to section 3.14.8
5. If all peaks are not detected, set the **Peak Threshold** limit to half the maximum power level of the FBG reflection peaks.
6. Set the **Peak Width** to approximately half the Full Width Half Max (FWHM) of the FBGs being interrogated
7. Click Start Scan (This may take up to a minute depending on the scan range). **Note:** If a large number of oscillations are visible in the reflection spectrum and the number of peaks does not match the number of gratings, the fibre or patch cord may be damaged.
8. Click More Detail (This may take up to a minute depending on the scan range)
9. Save the **Array Properties** (if you are using Automatic Control or Semi-automatic remember the name given to each array, as you will need to use this later)
10. You may also choose to record the spectral profile of the array as a text file and as an image for further analysis by clicking on the save button at the bottom of the scan window.
11. If there is more than one array in the set-up, go to Configuration tab again, and click on Reset Range. Repeat steps 1 to 10 in section 3.14, until all arrays required to be scanned are finished (remember to Reset Range for every array)

3.15 Automatic Control

1. Click the Enable button in the Automatic Control window on the bottom Right Hand Side (RHS) of the Scan tab window.
2. **Select Array List & Config**

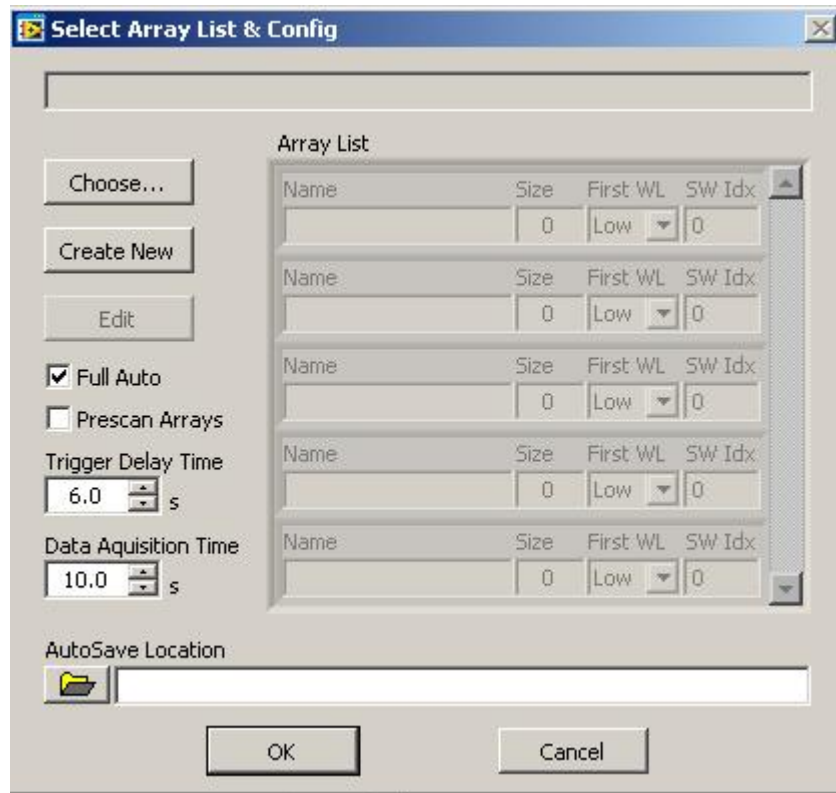


Figure 3.15.1: Array list Selector/Auto mode configuration

- i. Check 'Full Auto' box if you are using the interrogation system in automatic mode (Figure 3.15.1)
 - ii. Set the **Data Acquisition Time**: 28 s (this may be adjusted depending on the data acquisition requirement). **Note**: An additional 8 seconds on top of the acquisition window is required to allow the photovoltaic signal to settle between different optical switches. (For example, if 20 seconds is required to acquire the data, then set Data Acquisition Time to 28 seconds)
 - iii. Check the 'Prescan Arrays' box
 - iv. Click the folder which says AutoSave Location, and type in a name and click save (This will be the folder where all the results will be saved)
 - v. Click Create New
3. **Create/Edit array list**
 - i. In the first Name input field (Figure 3.15.2), type in the name of the *.xml file (just the core filename, not the extension) as saved previously in step 9, section 3.14
 - ii. Select the number of sensors on the array in the size window
 - iii. Select Low if the first sensor is at the lowest wavelength, select High if the first sensor is at the highest wavelength

- iv. Repeat steps i to iii in step 3, above, for other arrays (This is limited by the switchbox capacity. Arrays **MUST** be connected to the switchbox in the same order as they appear in this list)
- v. Click on save to save the list of arrays in the same folder as the configuration *.xml files
- vi. Click Finished to return to array list selector (Figure 2.15.1)
- vii. Click OK on the **Select Array List & Config** page to return to the Scan tab

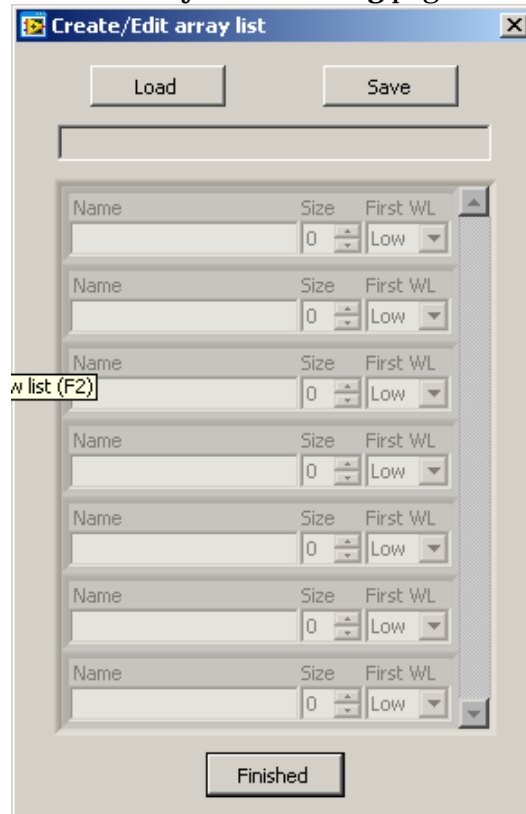


Figure 3.15.2: Array list editor

4. Automatic Control in the Scan tab

- Back in the Scan tab, the **Automatic Control** is shown as Figure 3.15.3, click start while the shaker is off

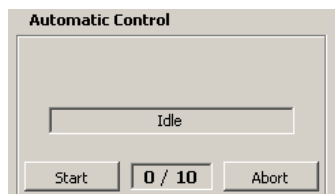


Figure 3.15.3: Automatic Control mode in idle stage

- Wait until the prescan is complete, this will take a few minutes depending on how many arrays are being utilised, during this time you can pause or abort. (see Figure 3.15.4)

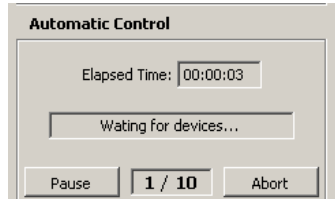


Figure 3.15.4: *Automatic Control* mode in prescan stage

Once the prescan is complete as seen in Figure 3.15.5, turn on the shaker and adjust the gain until the required force is reached. (If the red LED indicator is continuously on, decrease the gain until a red and green light flash intermittently) and then click continue. The shaker testing is now underway. The Interrogation software will interrogate each grating on the array for the user defined time interval before automatically switching to the next grating on the array (see Figure 3.15.6). This process continues until all the gratings on all the arrays have been recorded.

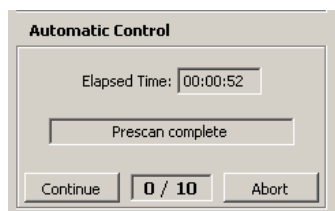


Figure 3.15.5: *Automatic Control* mode in complete pre-scan stage

Note: If there is no response to the shaker excitation from the photodiode as viewed on the OROS display window, check if the 'Laser Active' light is activated on the Agilent program.

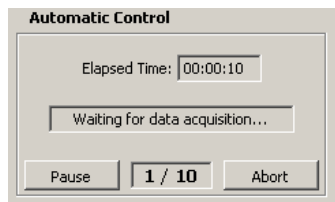


Figure 3.15.6: *Automatic Control* mode in data acquisition stage

When all the recordings have finished the automatic control window will display the total elapsed time for the whole test as shown in Figure 3.15.7.

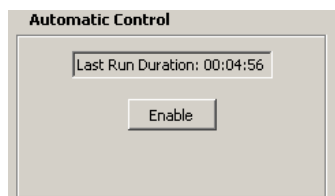


Figure 3.15.7: *Automatic Control* window upon completion of the test

4. LabView Programs to Analyse Experimental Results

The following is a list and brief description of some LabView programs which have been developed specifically to display and analyse the data for the Intensity Based Interrogation system.

4.1 Programs used to analyse results from the OROS



Result Viewer

Opens TXT files exported by OROS analyser

- For quick previewing and/or plotting of data



Wave Viewer

Reads WAVE files created by OROS Analyser.

View and export:

(with user definable averaging/windowing parameters)

- Time History
- FFT Spectrum
- FRF
- Coherence

Enables Calibration of FBG records using ARRAYLIST file

4.2 Programs used to analyse results from the Tuneable Laser



Data Export
Tool

View raw data in TLSCAN files

Limited export to text file (grating wavelength & calibration)

- Use "Export Calibration" instead of this for getting calibration factors



FBG Profiler

Viewer program for array scan files

- View results from wavelength scans (TLSCAN / ARRAYLIST)
 - View and export plots of individual FBGs or arrays
 - Re-run peak detection with different parameters on existing scan data
-

Export
Calibration

FBG calibration exporter.

- Preview and export FBG calibration factors from wavelength scan (TLSCAN / ARRAYLIST)
 - Allows modification of calibration range on each sensor before export.
 - Exports to text the calibration factors in units of Volts/microstrain
-

Import from
Swin
Interrogator

Converts data recorded by fibre interrogation system at Swinburne to TLSCAN format

- Performs automatic FBG detection and conversion from dB to linear scale
 - Enables data to be viewed with “FBG Profiler” program
-

Read Power
Log

Reads log file of power measurements from Tuneable Laser module.

- Log file records to “LabVIEW Data” folder
- Can be used to observe reflected power drift over time if “External Measurement” checkbox is deselected in laser control program

N.B. This software is still under development

4.3 Miscellaneous Analysis Programs



avg
coherence.vi

Plots average coherence from multiple OROS exported TXT files



change calib
length.vi

Recalculate calibration in TLSCAN files with new calibration length (i.e. change calibration range from 60pm to 30pm)

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19. ABSTRACT This technical note is provided as a companion document to DSTO TR-2370. The original technical report describes the development and evaluation of an intensity-based demodulation approach for the measurement of strains, induced by structural vibrations, using Fiber Bragg Gratings (FBG). This companion technical note contains a detailed set of operating instructions for interfacing the intensity based demodulation system with a frequency analyser to provide the Frequency Response Functions from a series of FBG arrays attached to a vibrating structure.					